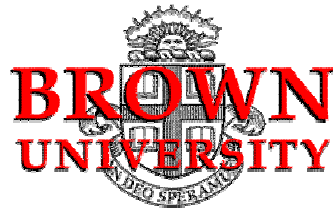


Probing Large Extra Dimensions in Collider Experiments

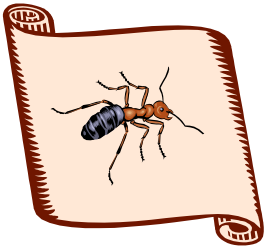
Greg Landsberg



APS 2000 Long Beach Meeting

May 1, 2000

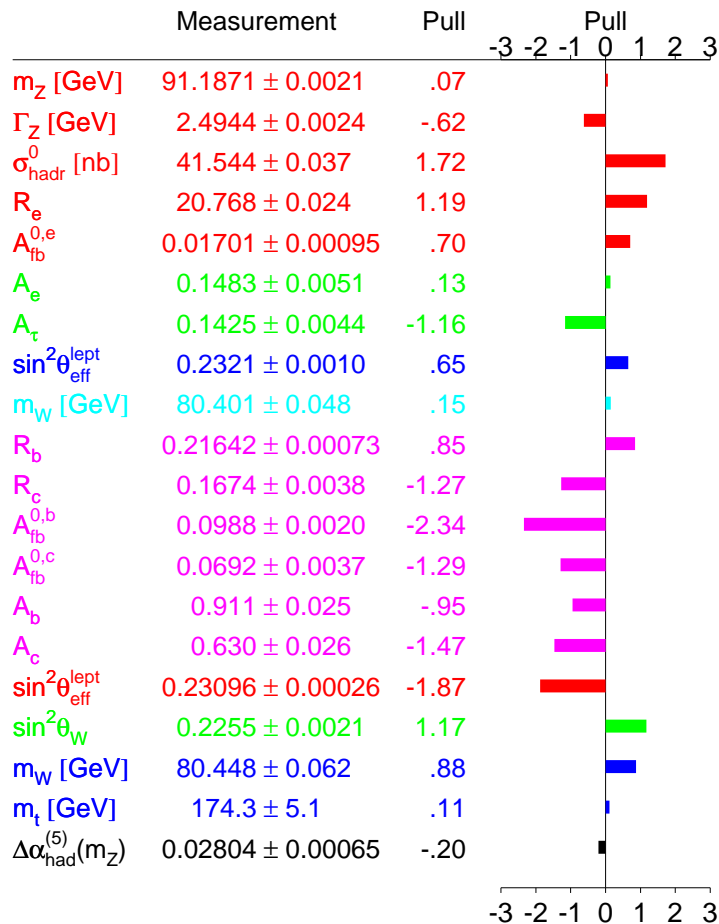
<http://www-d0.fnal.gov/~gll>



Standard Model: Beauty and the Beast

✚ ...beauty:

Moriond 2000



The Standard Model, based on just three parameters, is extremely successful in calculating dozens of physics quantities to a very high precision

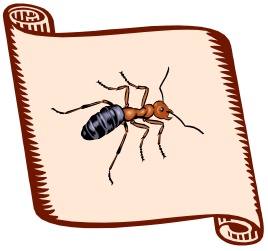


✚ ...and the beast:

✚ Standard Model accommodates, but does not explain:

- ✚ EWSB
- ✚ CP-violation
- ✚ Fermion masses

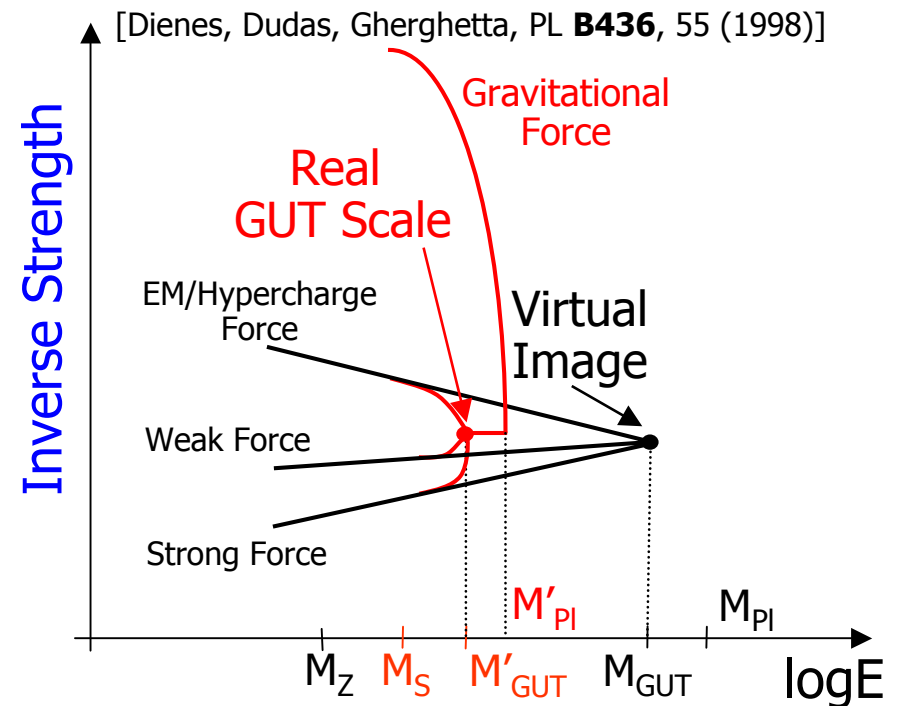
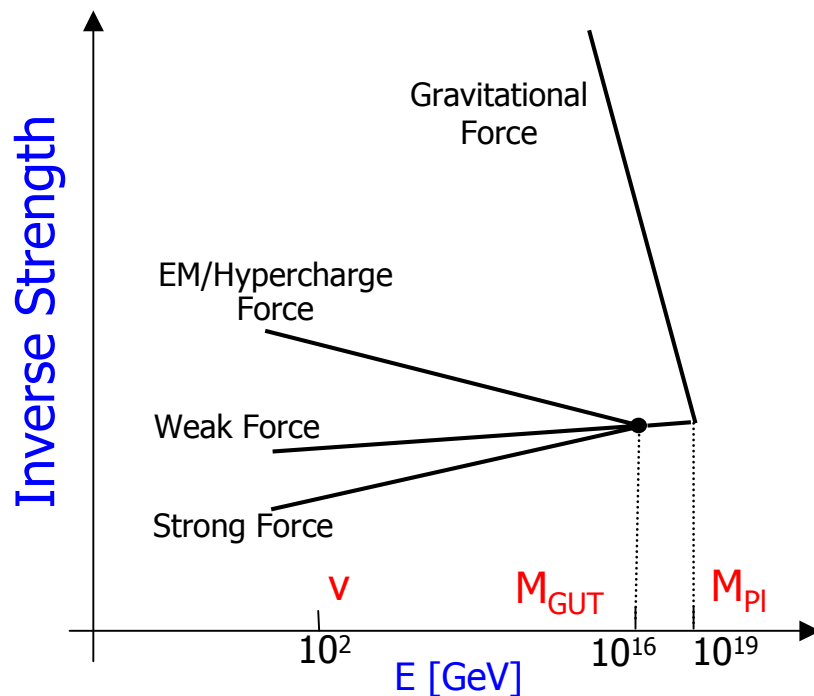
✚ In order for the SM to be an ultimate theory to the highest energies an extremely precise fine tuning of the parameters is required

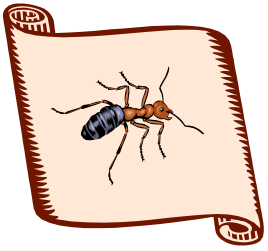


Life in the Bulk Space

- Standard picture of universe: all forces unify at very high energy, 10^{16} GeV, and gravity catches up at the Planck mass of 10^{19} GeV

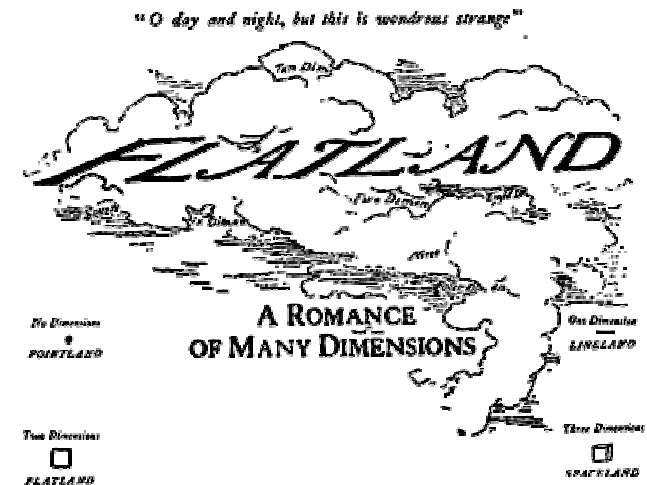
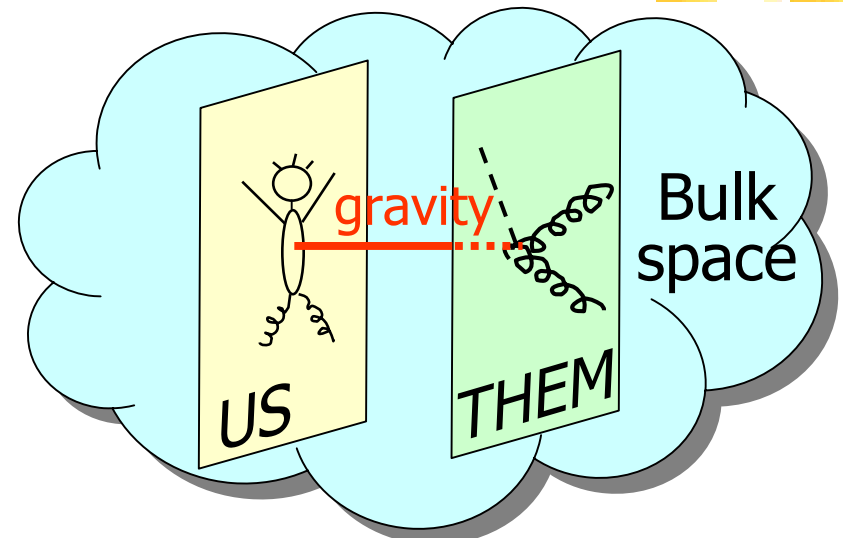
- Arkani-Hamed, Dimopoulos, Dvali (ADD) (1998): what if the scale of unification is only ~ 1 TeV?!!

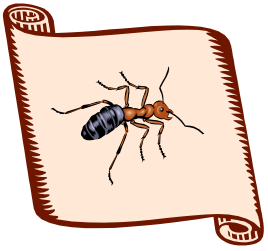




Physics of Large Extra Dimensions

- ✚ Bringing **unification scale to 1 TeV** allows for a **very rich physics**, possibly filling in the gaps left by the Standard Model
- ✚ **First alternative** to the “established” post-Standard-Model theories **in 25 years!** – What took us so long?
- ✚ A **significant theoretical interest** to the subject ensures rapid development of this field
- ✚ Close to **300** theoretical **papers** on this subject over the past two years – truly a **topic du jour**
- ✚ This new theory, if proved right, **could be the most significant discovery of human mind since** we managed to realize that **the Earth is not flat**
- ✚ Cf. **Edwin Abbot’s “Flatland” (1884)**





An Importance of Being Compact

✚ What about **Newton's Law**?

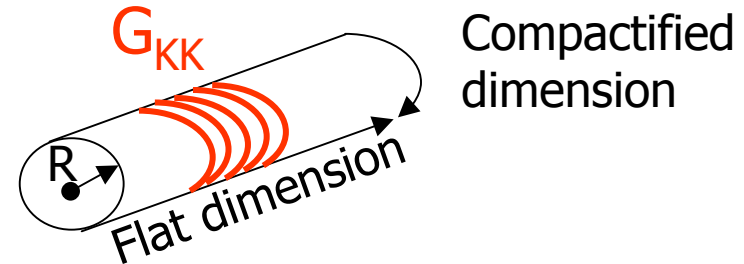
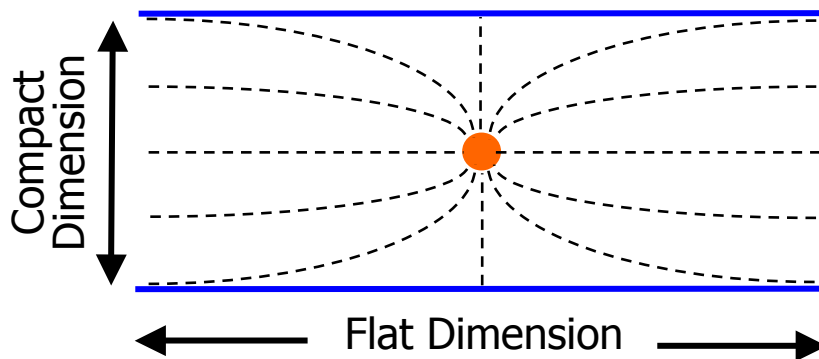
✚ $n=3$: $F \sim 1/r^2$

✚ $n=3+\delta$: $F \sim 1/r^{2+\delta}$

✚ This is **only true** for “flat” or infinite dimensions!

✚ If **extra dimensions are curled-up**, or compactified, with the radius R , the $1/r^{2+\delta}$ law works only for distances $r \ll R$

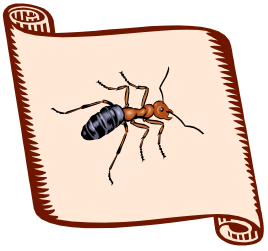
✚ For $r \gg R$ we still have usual $1/r^2$ law



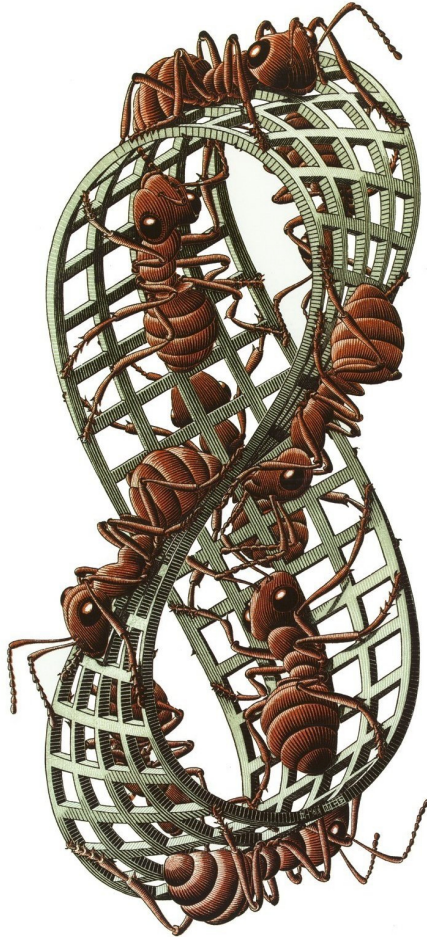
✚ Compactified dimensions offer a way to **increase tremendously gravitational interaction** due to a large number of the available “winding” modes

✚ This tower of excitations is known as **Kaluza-Klein modes**, and such gravitons propagating in the compactified extra dimensions are called Kaluza-Klein gravitons, G_{KK}

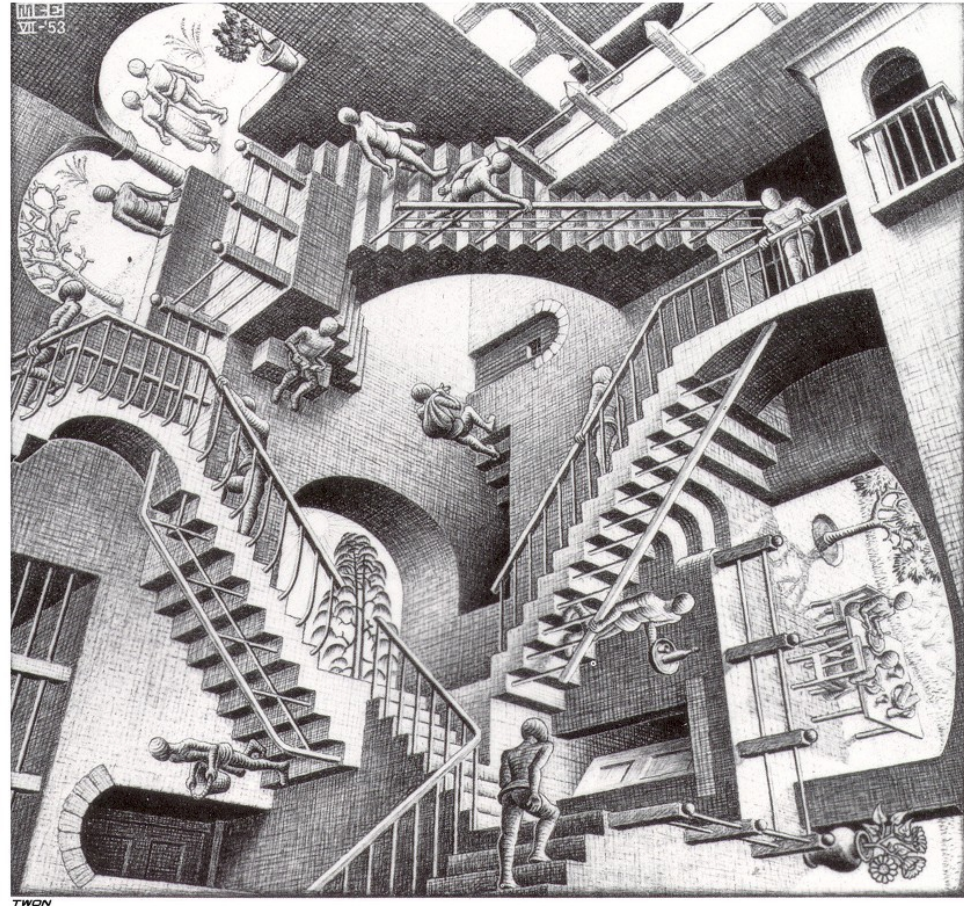
✚ The **higher the energy** is, the more turns a graviton can make, and the **stronger gravity** becomes



Examples of Compactified Spatial Dimensions



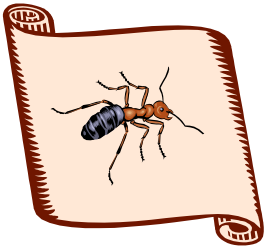
M.C. Escher, Mobius Strip II (1963)



M.C. Escher, Relativity (1953)

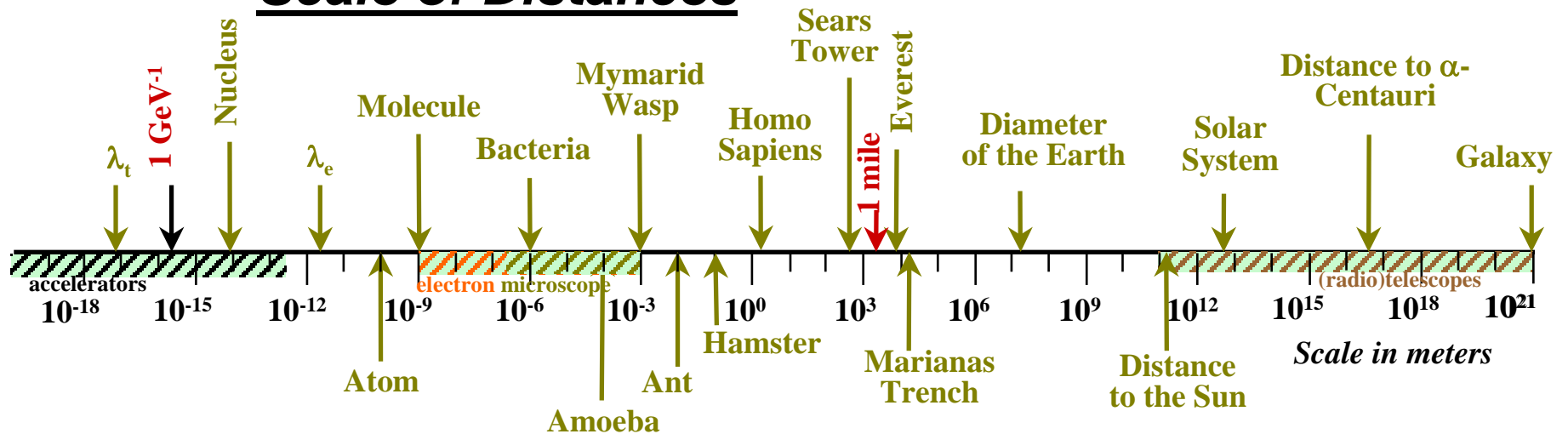
[All M.C. Escher works and texts copyright © Cordon Art B.V., P.O. Box 101, 3740 AC The Netherlands. Used by permission.]

Press Conference, May 1, 2000 Greg Landsberg, Probing Large Extra Dimensions at Colliders



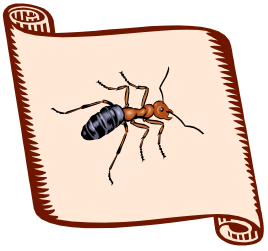
Scales, Scales, Scales...

Scale of Distances



- Particle **accelerators** (colliders) are the **finest microscopes** we have ever built
- While **tabletop experiments** are important tests of Newton's law at short distances, **collider experiments** are **complementary** as they are capable of probing gravity at much shorter range

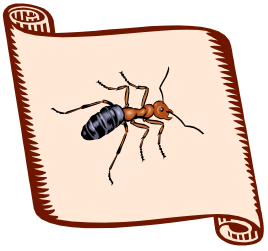
$$R \propto \begin{cases} 8 \times 10^{12} m, & n = 1 \\ 0.7 mm, & n = 2 \\ 3 nm, & n = 3 \\ 6 \times 10^{-12} m, & n = 4 \end{cases}$$



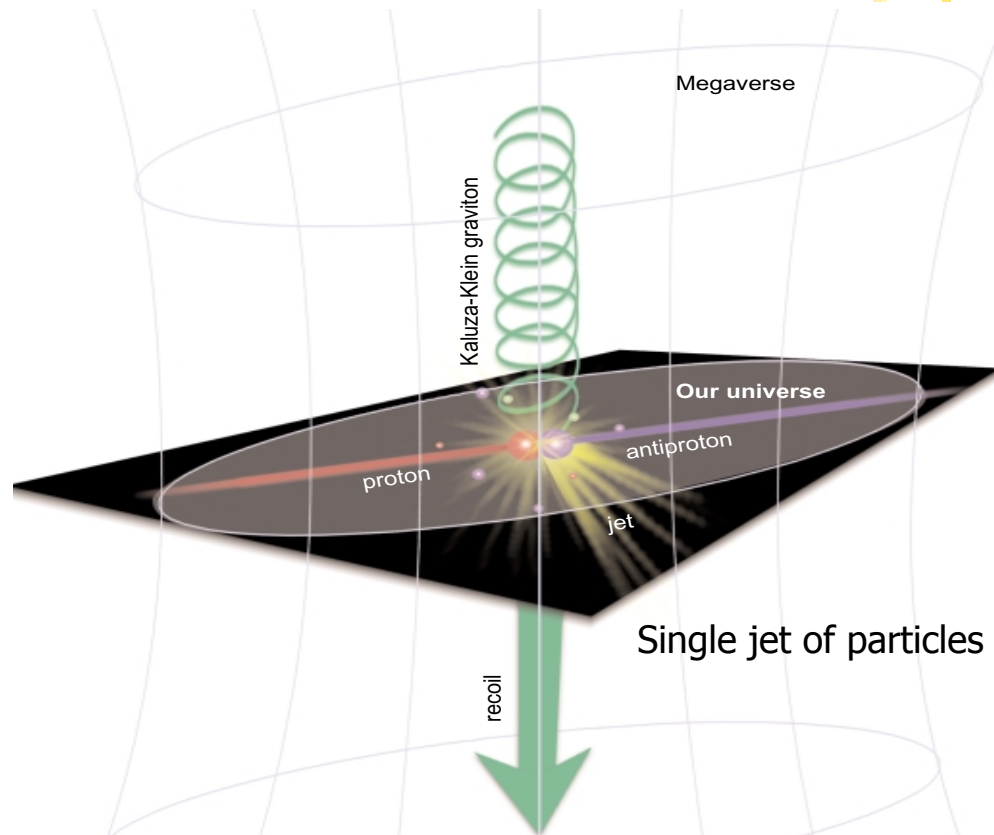
Modern Collider Experiments

- ✚ **LEP2: electron-positron collider at CERN**, near Geneva, Switzerland
 - ✚ Colliding beams have energy of about **100 GeV** each
 - ✚ Four experiments: **ALEPH, DELPHI, L3, and OPAL**
- ✚ **Tevatron: proton-antiproton collider at Fermilab**, near Chicago, U.S.
 - ✚ Colliding beams are accelerated to nearly **1000 GeV**
 - ✚ **Highest energy** man-made **accelerator** to date
 - ✚ Two experiments: **CDF and DØ**



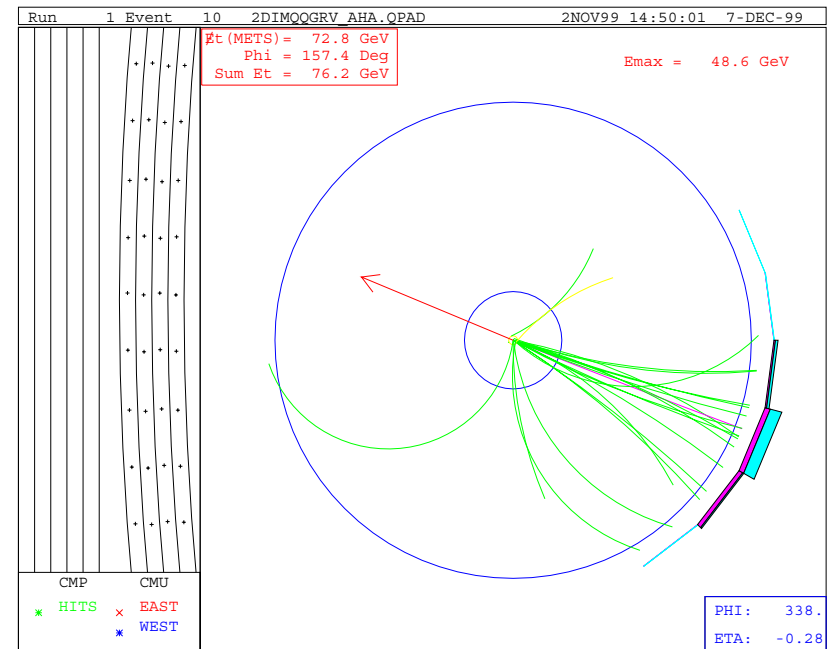


Looking for Extra Dimensions at Colliders

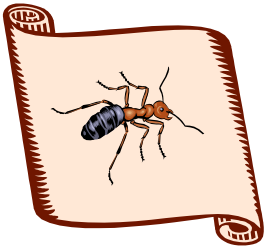


Graviton produced in high-energy collisions could leave our world forever, resulting in an apparent energy non-conservation...

Computer simulation of how such an event would've looked like in a collider detector (courtesy M.Spiropulu)

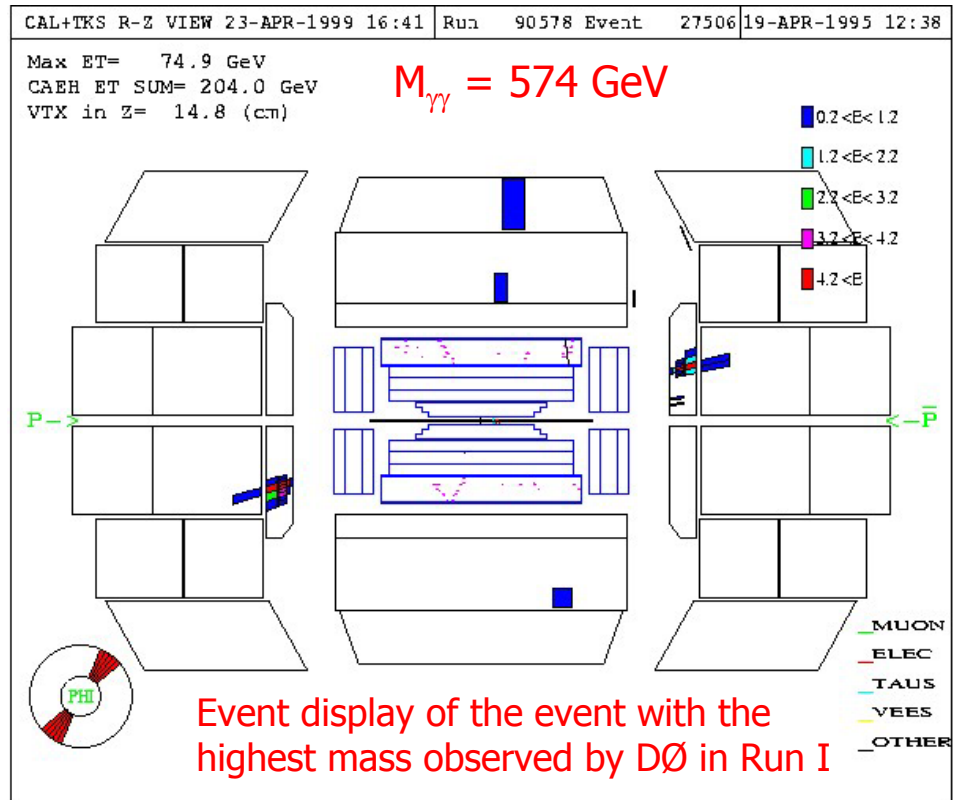
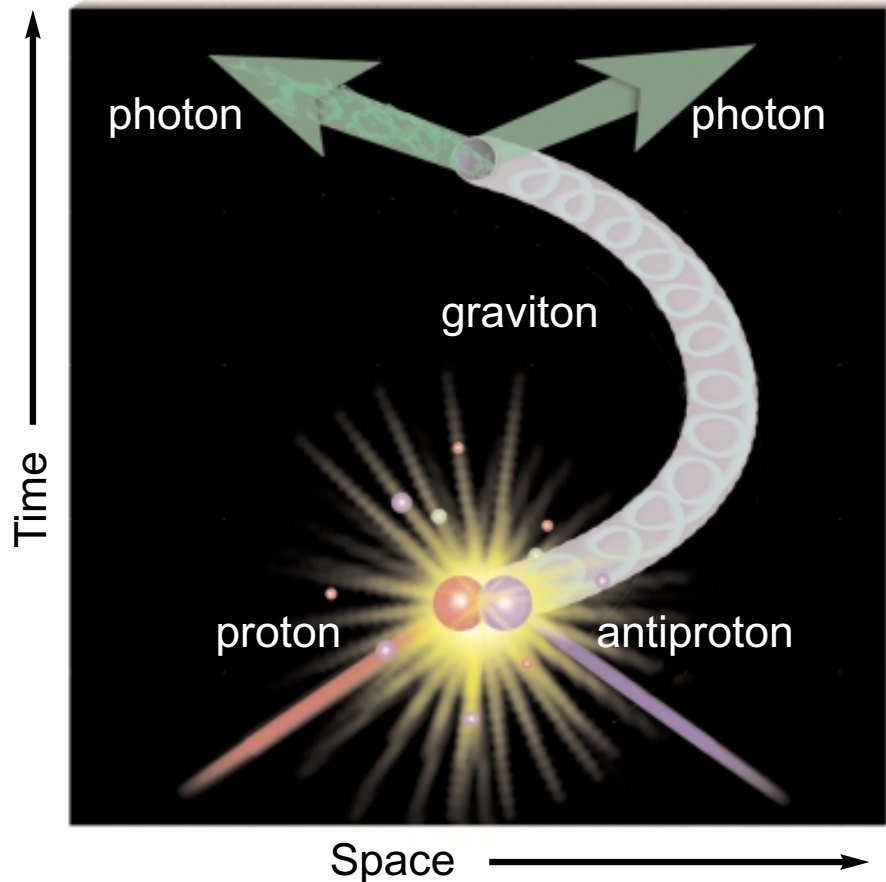


[Detector slice transverse to the colliding beams]

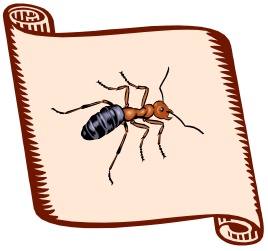


Looking for Extra Dimensions at Colliders

Graviton leaves our world for a short moment, just to reappear again and decay...

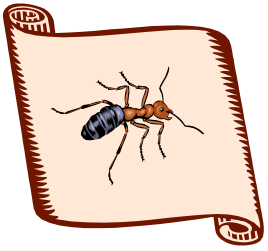


Unfortunately, the topology of this event makes it very unlikely candidate in graviton decay. Most likely it is due to well-established physics processes



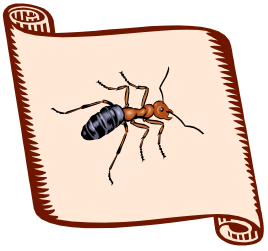
Recent Results from Colliders

- ✚ LEP2 Collaborations looked at both processes and have not seen any characteristic events due to strong gravity
 - ✚ Current limits on the unification scale from LEP2 is ~ 1 TeV
- ✚ The DØ experiment at Fermilab has just finished search for pairs of photons and electrons; no events typical of strong gravity have been seen
 - ✚ Current limits from DØ are similar to those from LEP2, although slightly higher
- ✚ Higher energy of the Tevatron, compared to LEP2, allows to increase the sensitivity by a factor of 2-3 in the next Tevatron run, just due to higher number of proton-antiproton collisions that we will collect
- ✚ This puts Tevatron in the unique position of finding extra dimensions in the next few years or significantly constrain the new model
- ✚ Both CDF and DØ are working on search for “monojets” due to graviton emission in the extra dimensions
- ✚ Further generation of colliders (LHC, NLC ?) will be able to probe unification scale up to 8-10 TeV, and thus allow for ultimate test of theory of extra dimensions



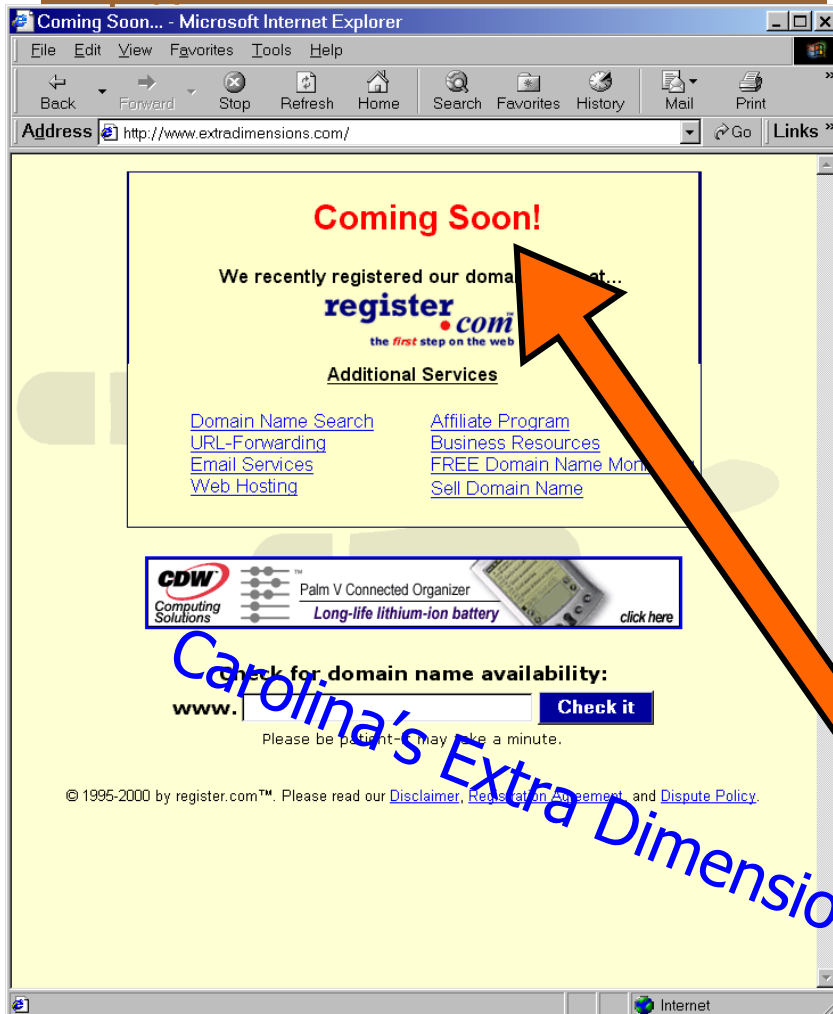
Black Hole Production at Future Colliders?

- ✚ If the energy of the collider exceeds the unification scale, gravity becomes so strong that colliding particles will form a microscopic black hole
- ✚ Not to worry: it lives for just a tiny moment and can not possibly interact with matter around it!
- ✚ The best prove is our own existence, since such black holes would be constantly produced by high energy cosmic rays
- ✚ These decaying black holes could produce spectacular events in future collider experiments, and we are looking at this possibility in more details
- ✚ Black hole production in the lab would be a unique achievement, helping us to solve the ultimate puzzle: origin of the universe and our very existence



Conclusion: WWW Search for Extra Dimensions

<http://www.extradimensions.com>



On 2/15/00 patent 6,025,810 was issued to David Strom for a "hyper-light-speed antenna." The concept is deceptively simple: "The present invention takes a transmission of energy, and instead of sending it through normal time and space, it pokes a small hole into another dimension, thus sending the energy through a place which allows transmission of energy to exceed the speed of light." According to the patent, this portal "allows energy from another dimension to accelerate plant growth."
- from APS "What's New", 3/17/00

Extra Dimensions TV Show

Stay tuned – next generation of collider experiments has a good chance to solve the mystery of large extra dimensions!